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Metabolic Engineering of Crops for Drought and Salt Tolerance

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Drought, or insufficient water, is the single most important factor limiting U.S. crop productivity, and salinity is another important constraint, especially for irrigated crops. Scientists predict that these environmental stresses will become even more serious in future years as aquifers are drawn down, as competition between agricultural and nonagricultural water use intensifies, and as the global climatic warming trend continues.

Although most major crops are sensitive to drought and salinity, a few — such as sugar beets and cotton, as well as many wild species — grow relatively well under dry or saline conditions. In the late 1970s and early 1980s, researchers identified a major drought- and salt-tolerance mechanism in such plants: the production of high levels of compounds known as osmoprotectants. These compounds reduce drought- and salt-stress damage to plant cells.

UF/IFAS Photo: Thomas Wright

University of Florida researchers Andrew Hanson and Michael Nuccio examine transgenic tobacco plants. The plants have been genetically engineered to produce small amounts of glycine betaine.

Glycine Betaine

One of the most effective osmoprotectants is glycine betaine, a substance that occurs naturally in spinach, sugar beets, and cotton as well as in many highly salt- or drought-tolerant wild plants. However, many stress-susceptible crops (including most fruits and vegetables) do not contain significant amounts of glycine betaine or other osmoprotectants.

Since the mid-1980s, scientists have sought to use recombinant DNA techniques, or metabolic engineering, to increase plants' drought and salt tolerance by giving them the ability to produce glycine betaine. To accomplish this, researchers have needed to find the metabolic pathway by which plants produce glycine betaine, identify the enzymes that catalyze the biochemical reactions

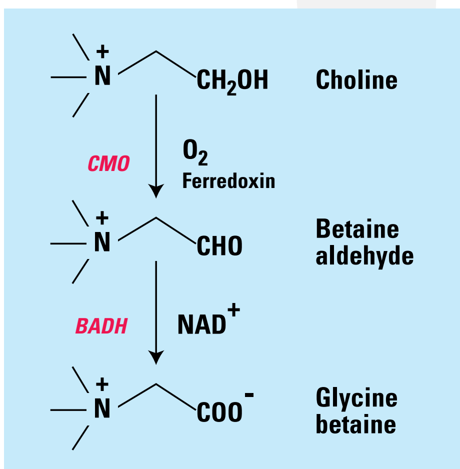
By enabling a plant to create an osmoprotectant, the researchers have confirmed that metabolic engineering of crop stress tolerance is possible.

involved, and clone the genes that code for these enzymes.

Synthesis Pathway

As part of research funded by the National Research Initiative (NRI) Competitive Grants Program, scientists at the University of Florida have identified the pathway by which spinach and sugar beets synthesize glycine betaine (see diagram below) and have isolated clones for both enzymes of the pathway. The two enzymes, choline monooxygenase (CMO) and betaine aldehyde dehydrogenase (BADH), are located in the chloroplast — the plant cell structure in which photosynthesis occurs.

Also needed for glycine betaine production are oxygen and reduced ferredoxin (a plant protein), both of which are generated during photosynthesis. It is known that glycine betaine is produced fastest when it is needed most — in bright light, when photosynthetic activity is greatest and when stresses can result in the heaviest damage to the plant.



PATHWAY FOR THE SYNTHESIS OF GLYCINE BETAINE, A SUBSTANCE KNOWN TO REDUCE DROUGHT AND SALT DAMAGE TO PLANT CELLS.

Metabolic Engineering

Recently, the researchers have begun introducing genes for CMO and BADH into tobacco, a commonly used model system. Although tobacco does not naturally accumulate glycine betaine, the transgenic plants already are accumulating small amounts of the substance.

These levels may be sufficient to give measurable protection from stress damage. However, because the glycine betaine levels in the transgenic tobacco are only a few percent of those in plants such as sugar beets and cotton, the researchers' long-term goal is to raise the glycine betaine level by further metabolic engineering. One promising approach may involve the use of genetic engineering to increase the plant's capacity to produce more choline.

By enabling a plant to produce an osmoprotectant, the researchers have confirmed that metabolic engineering of crop stress tolerance is possible. Their next research task is to learn how to engineer higher osmoprotectant levels in the tobacco plant and to extend this engineering concept to other major U.S. crops. ❖

The research reported in this factsheet was sponsored by the Natural Resources and the Environment Division of the National Research Initiative Competitive Grants Program. To be placed on the mailing list for this publication or to receive additional information, please contact the NRI (202/401-5022 or NRICGP@reeusda.gov). The factsheet also is accessible via the NRI section of the Cooperative State Research, Education, and Extension Service website at http://www.reeusda.gov/nri